RESEARCH & DEVELOPMENT

Instant Air Meter Measurement of Air Content in Fresh Concrete

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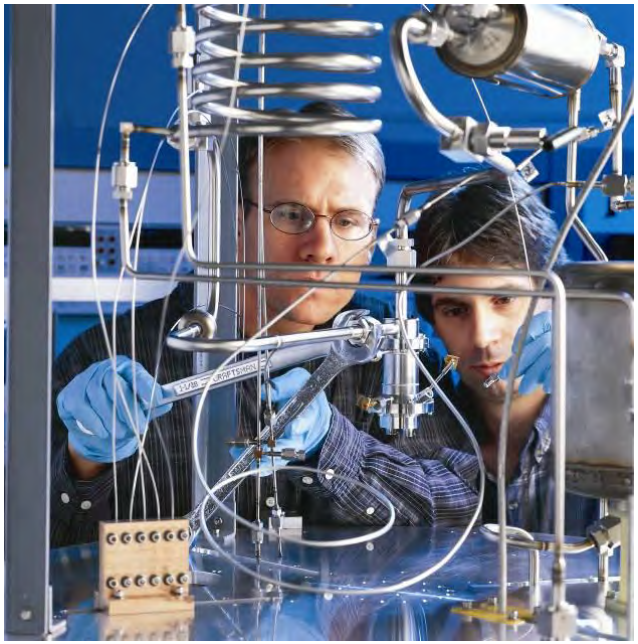
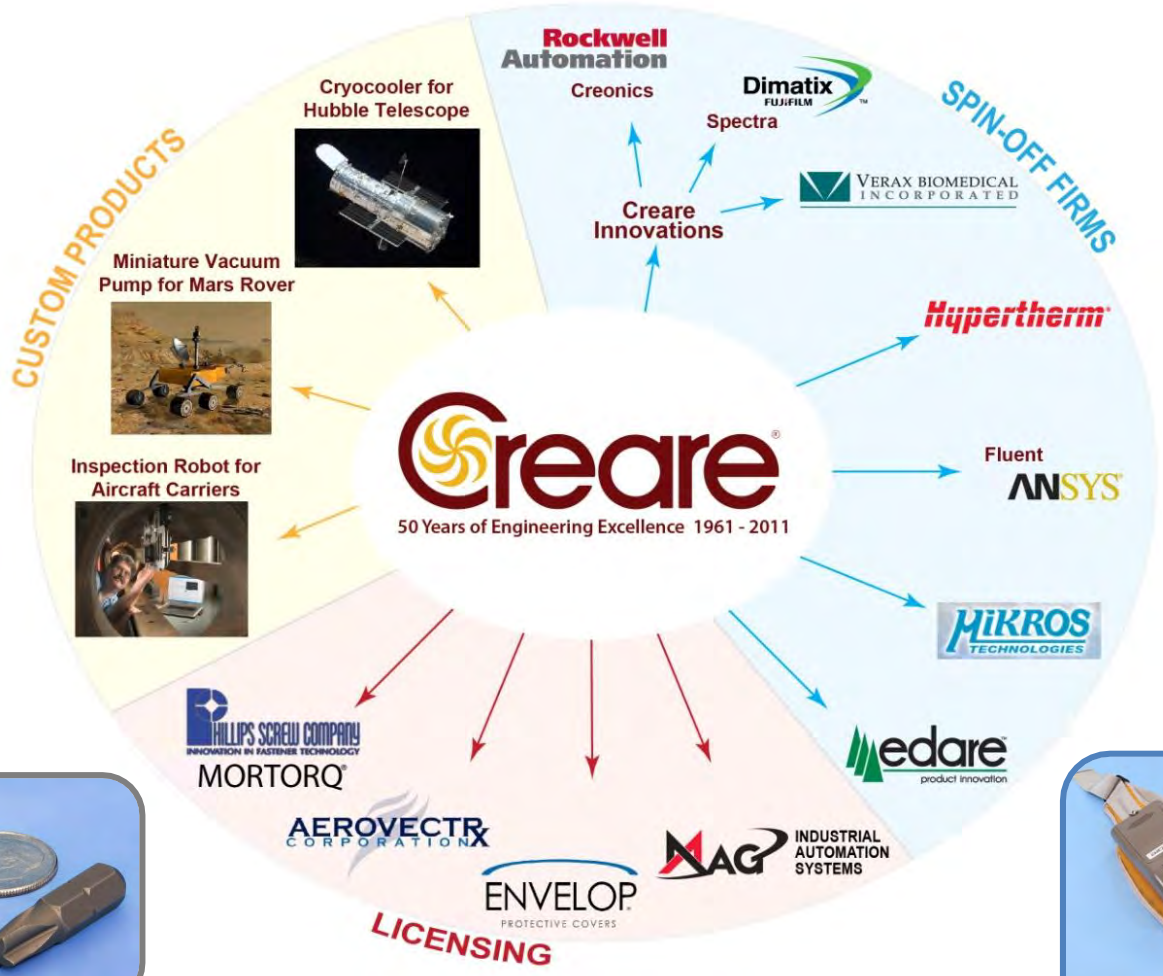
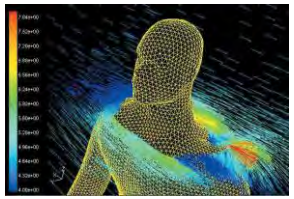
Corporate Profile

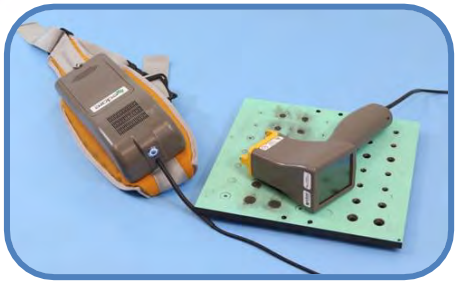
- Contract Engineering R&D
- Hanover, NH
- Industrial and Federal Client Base
- Founded in 1961
- Owned by Partnership of Engineers
- 160+ Employees
  - 70+ Engineers (55% Ph.D., 30% M.S.)
  - 40 Technicians, Machinists, Drafters (30% B.S., 30% A.S.)
- Technology Commercialization
  - Licensing
  - Spin-Off Companies
  - Custom Products



Technology Commercialization







Creare Spin-Offs Employ 2,300 and Generate Over $475M in Annual Revenues

Overview

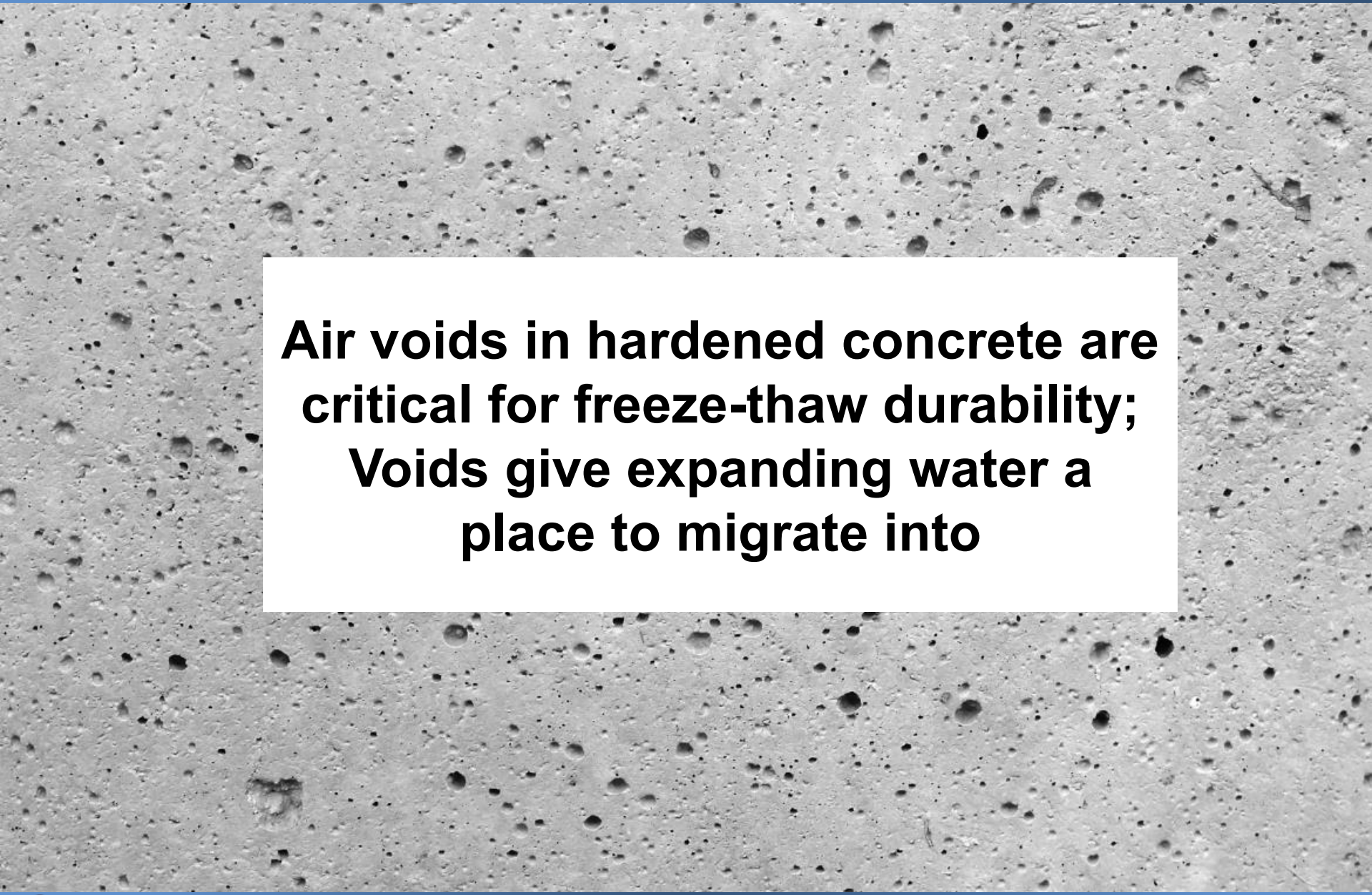
- **SWAM** – Shock Wave Air Meter
  - **Total Air** and **Specific Surface** in fresh concrete
  - More accurately predict **Hardened Spacing Factor**
  - Handheld
  - Instantaneous
- Improve QC
  - Quality
  - Frequency

SWAM

Technology Status

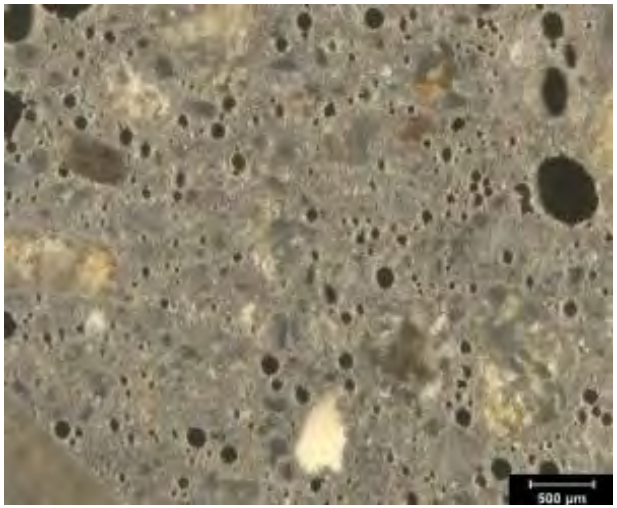
- **Early Development**
- **One Prototype, In Flux**
- **Seeking Industry Feedback and Input**

Concrete Air Quality



Air voids in hardened concrete are critical for freeze-thaw durability; Voids give expanding water a place to migrate into

Air Void Parameters



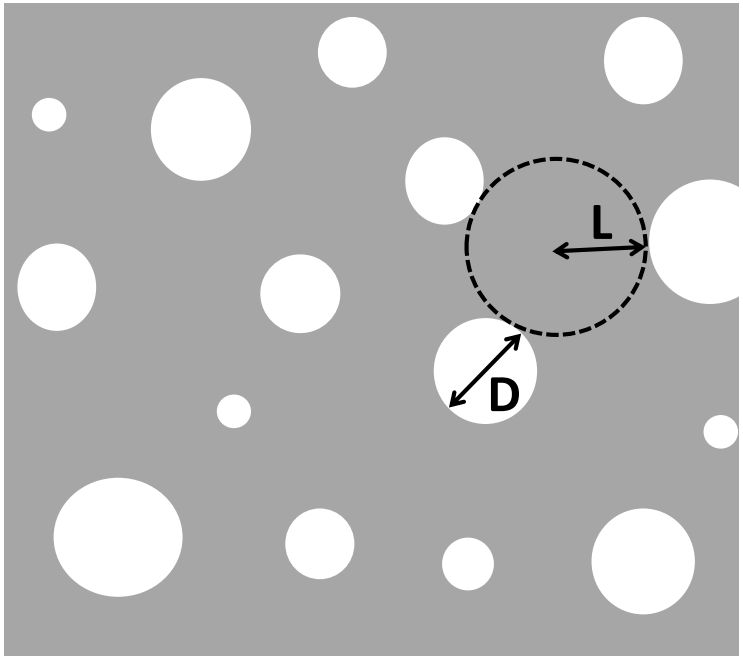
Number Density: $n = \#/\text{in}^3$

Total Air: $VF = n\overline{D^3}$

Specific Surface: $SS = \frac{D^2}{D^3} = \overline{D^{-1}}$

Spacing Factor: $SF = \bar{L} \approx \frac{PF}{SS \cdot VF}$

Powers, T.C. Proc. Highway Res. Board, 1947
Snyder, Adv Cem Bas Mat, 1998



- **Spacing Factor is what matters**
  - Target typically SF ≤ 0.008″
- Cannot measure SF fresh
- Can infer by measuring VF and SS
- In static concrete, SF more likely to be stable
  - When bubbles grow/shrink, VF and SS move in opposite directions

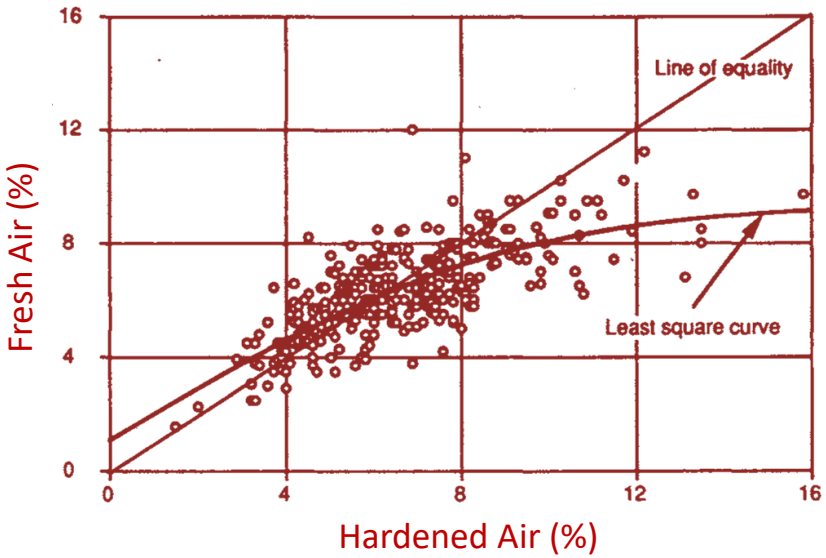
Existing Measurement Methods

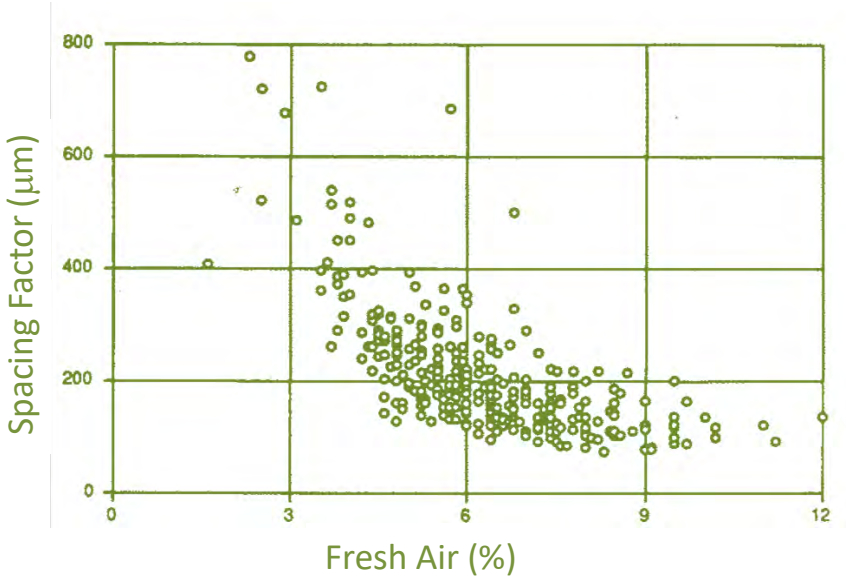
- **Hardened Petrographic Analysis**
  - ASTM C457
  - Expensive, delayed

- **Fresh Air**
  - ASTM C231 Pressure
  - ASTM C138 Gravimetric
  - ASTM C173 Volumetric

- **Fresh, Additional Parameters**
  - Germann AVA-3000
  - Super Air Meter

Fresh Total Air Measurement



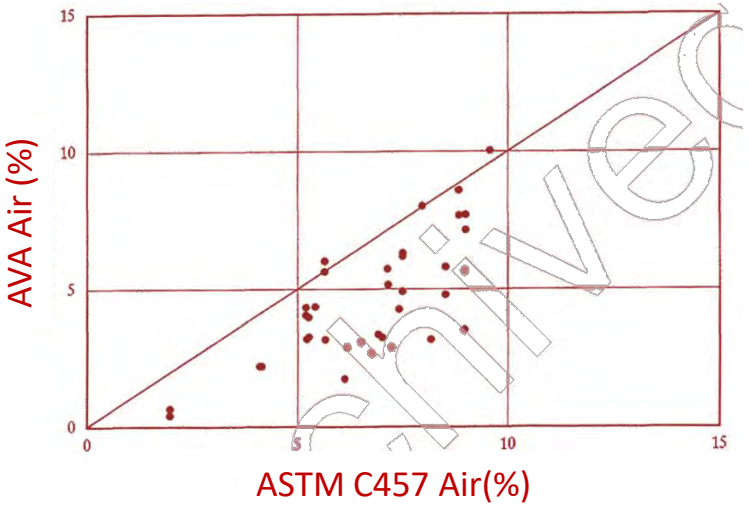


C231 Pressure Meter most common

- **Trained technician, 5−10 minutes**
- **Ideal accuracy: ~ ± 0.8 percentage points**
- **Correlation to hardened air: ~ ± 2 percentage points**
- **SF prediction uncertainty > ± 0.004″ (100 μm)**

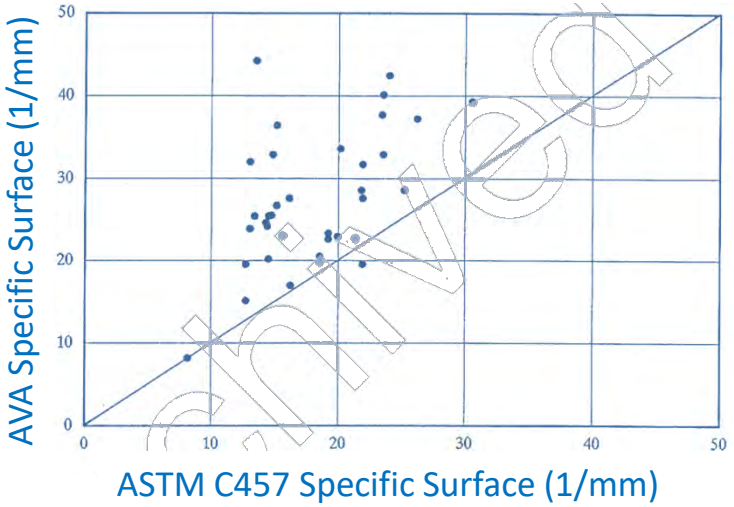
Saucier, Pigeon, and Cameron, ACI Mat. J. (1991)

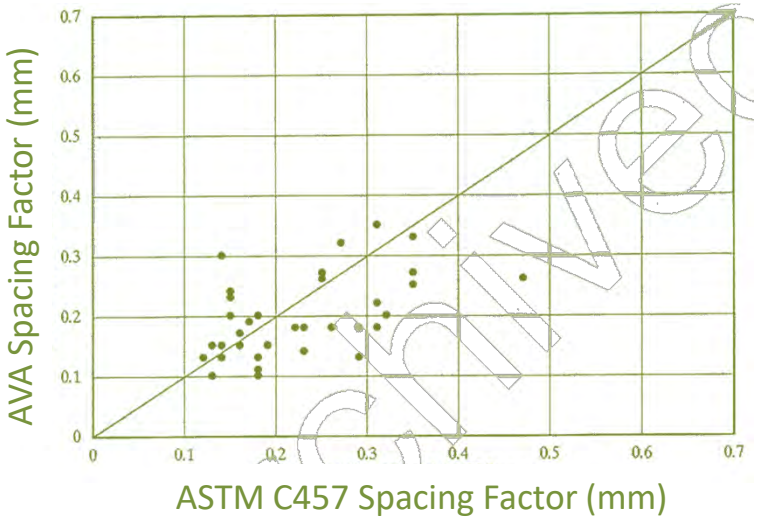
AVA – Predicting Hardened Properties



- **Poor correlation to hardened**
- **Uncertainty (bias-corrected):**
  - **Air:** **> ± 2 percentage points**
  - **SS:** **> ± 250 in.$^{-1}$ (10 mm^{-1})**
  - **SF:** **> ± .004 in. (100 μm)**

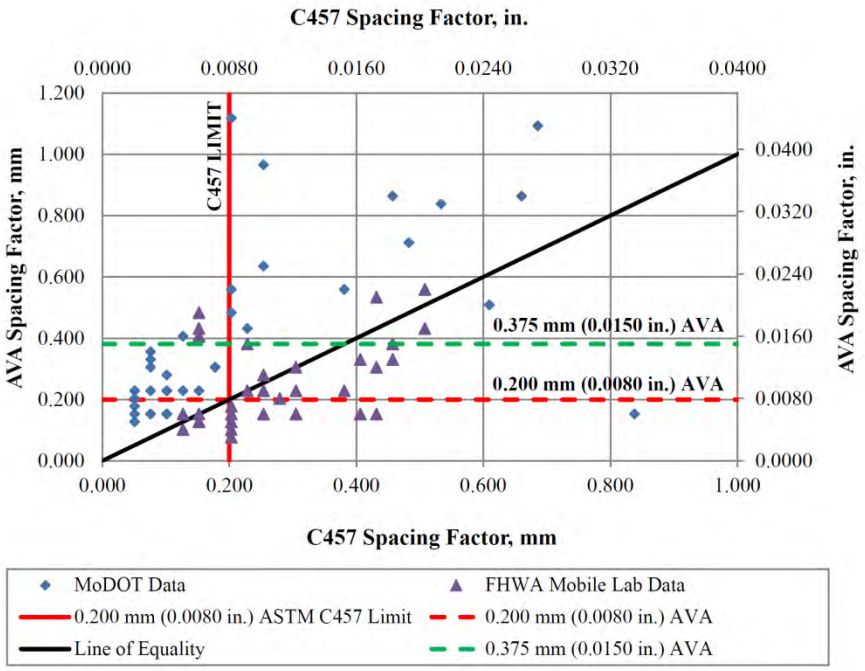
Magura, D.D., FHWA-SA-96-062 (1996).



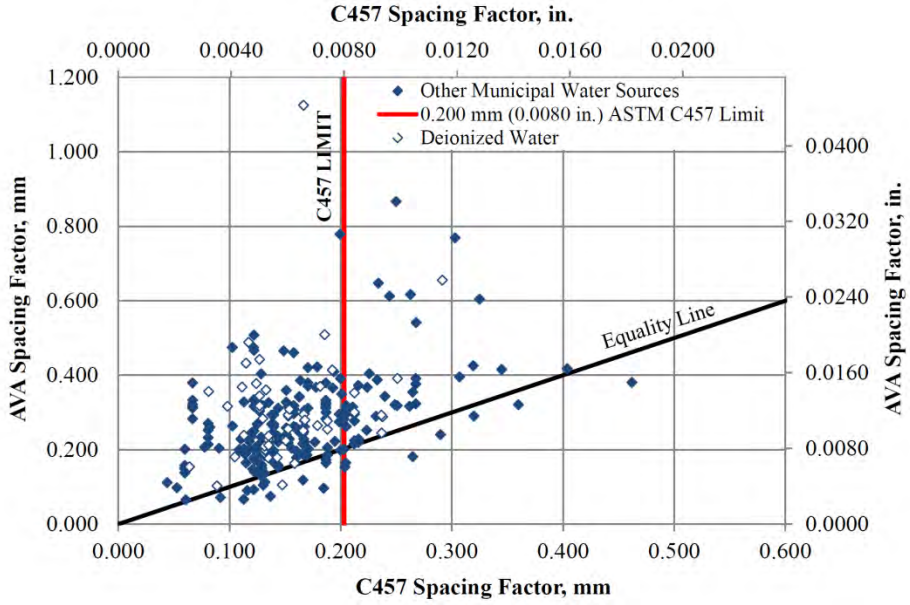


AVA - Predicting Hardened Spacing Factor

- **Very weakly correlated**
- **Uncertainty (bias-corrected): ~ ± 0.008″ (200 µm)**



Wang, K., Mohamed-Metwally, M., Bektas, F., & Grove, J. (2008). FHWA Report No. DTFH-61-06-H-00011, W03



Lindquist, W., Montney, R. (2015). FHWA-KS-15-10

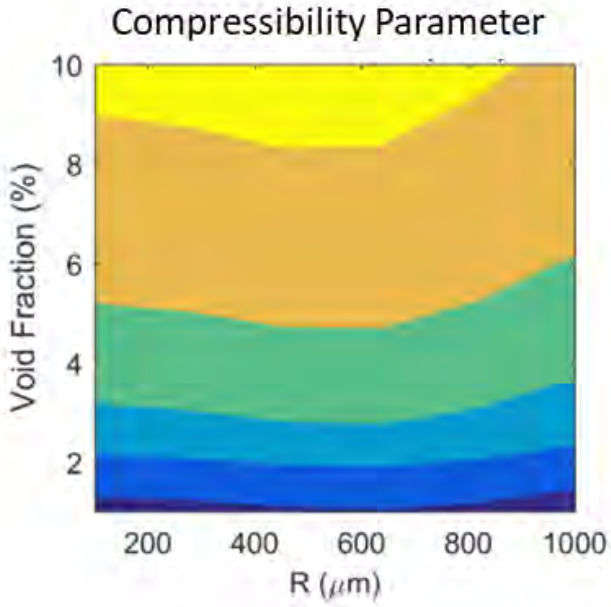
Problem Summary

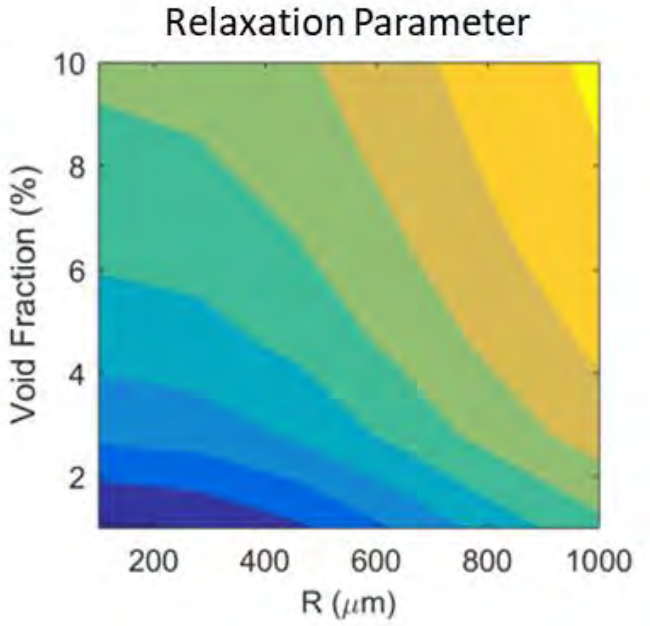
- What matters (physically) is **Hardened Spacing Factor**
  - Typical target ≤ **0.008″**
  - Need to predict when fresh
- Fresh Air – Pressure Meter
  - 5–10 minutes, effortful, tedious
  - Hardened Spacing Factor uncertainty ≥ 0.004″
- AVA
  - 25 minutes, mortar separated by agitation
  - Hardened Spacing Factor uncertainty ± 0.004 – 0.008″
- Super Air Meter
  - 10 minutes, more tedious
  - Tanesi, FHWA (2016): “… better correlation between fresh air content and spacing factor than … between SAM number and spacing factor”

SWAM Instrument

Principle of Operation

- Piston coupled to fresh concrete
- Shock wave launched into the concrete
- We measure a compressibility and relaxation time parameter
- Compressibility related to total air
  - Bubbles are squishy!
- Relaxation time related to bubble size (specific surface)
  - Small bubbles respond quickly
  - Large bubbles take more time





SWAM Use

GT Experiments

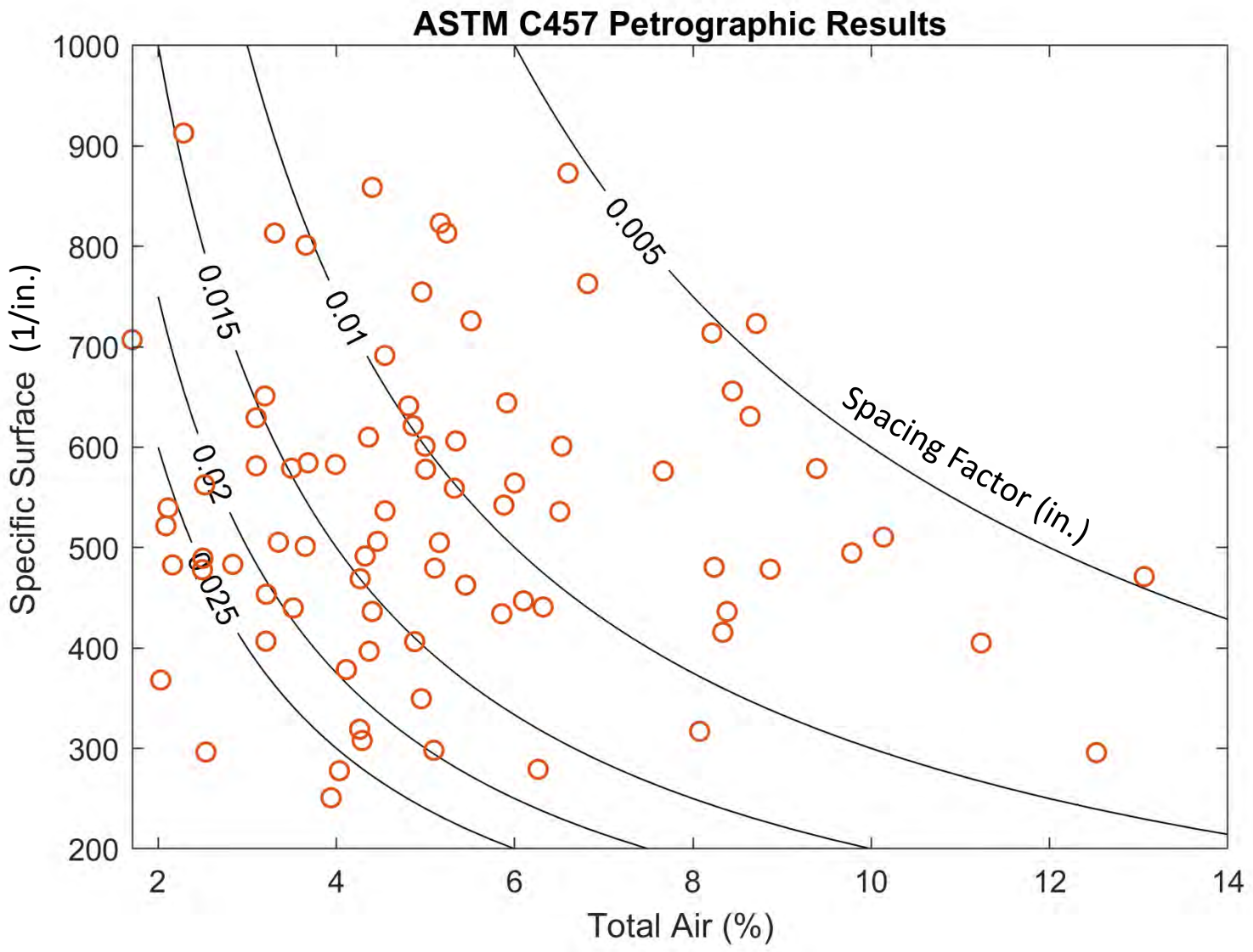
Test Matrix

- **Georgia Tech – Kim Kurtis, Scott Smith**
- **83 total mixes, typical of transportation projects**

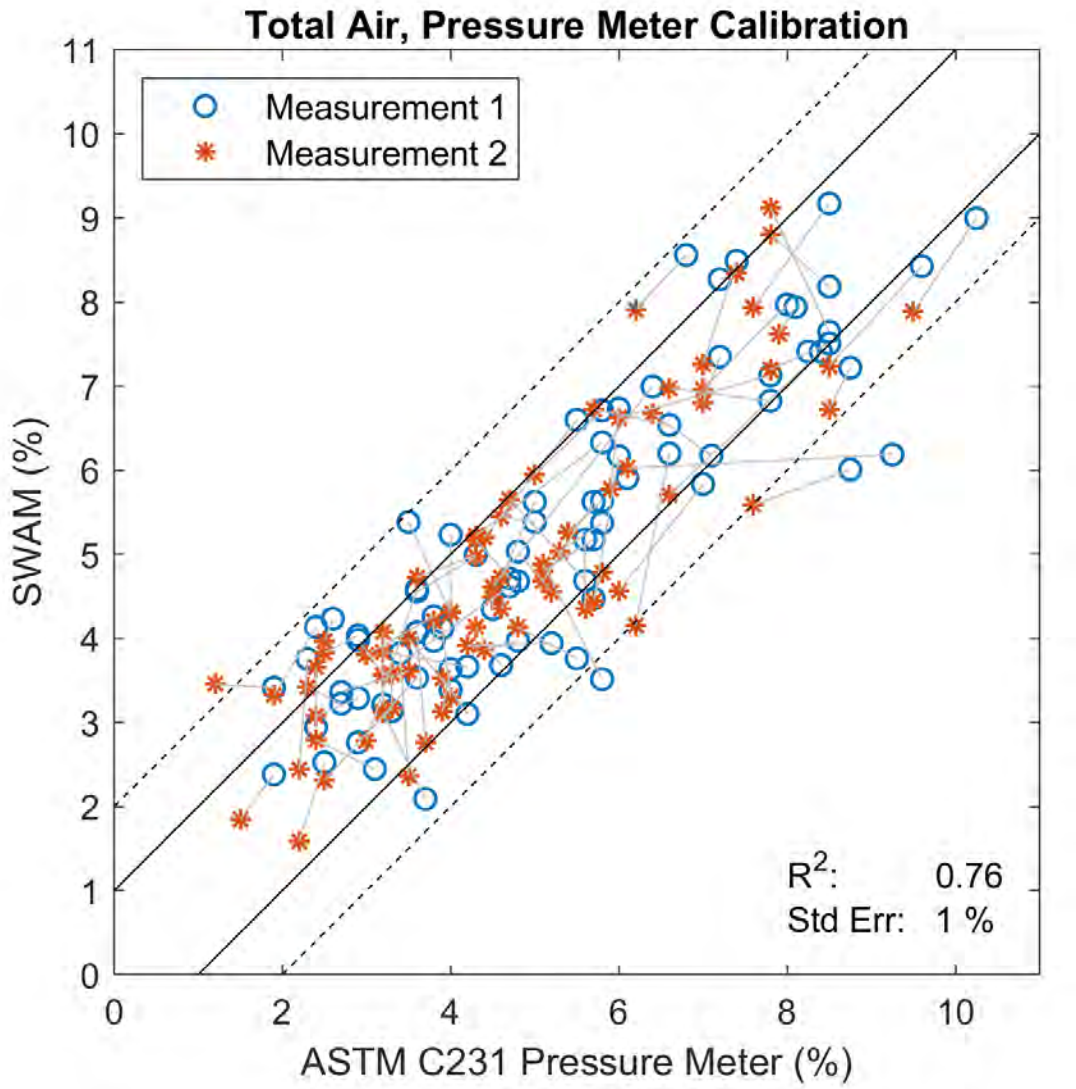
Parameter	Category #1: 64 Mixtures	Category #2: 9 Mixtures	Category #3: 8 Mixtures
w/cm (lb/lb)	0.40, 0.45, 0.50, 0.55	0.45	0.45
Design Air Content (%)	2, 4, 6, 8	4	4[2]
Coarse Aggregate Volume Fraction (%/100)	0.62, 0.70	0.62, 0.66, 0.70	0.66
NMAS (in) (Gradation (#))	1" (#57),	0.75 (#6), 1 (#57), 1.25 (#4)	#57
SCM Type	N.A.	N.A.[1]	Class F and C Fly Ash, Limestone Powder, Slag[2]
SCM Replacement (% wt. of OPC). (%)	N.A.	N.A.	20 and 40
Admixture Combination	AEA, AEA + WRA	AEA	AEA

1. For replicate mixtures from Category #1, OPC will be replaced by Class F Fly Ash by 20% by mass.
2. For replicate mixtures from Category #2, design air content will be 6%.

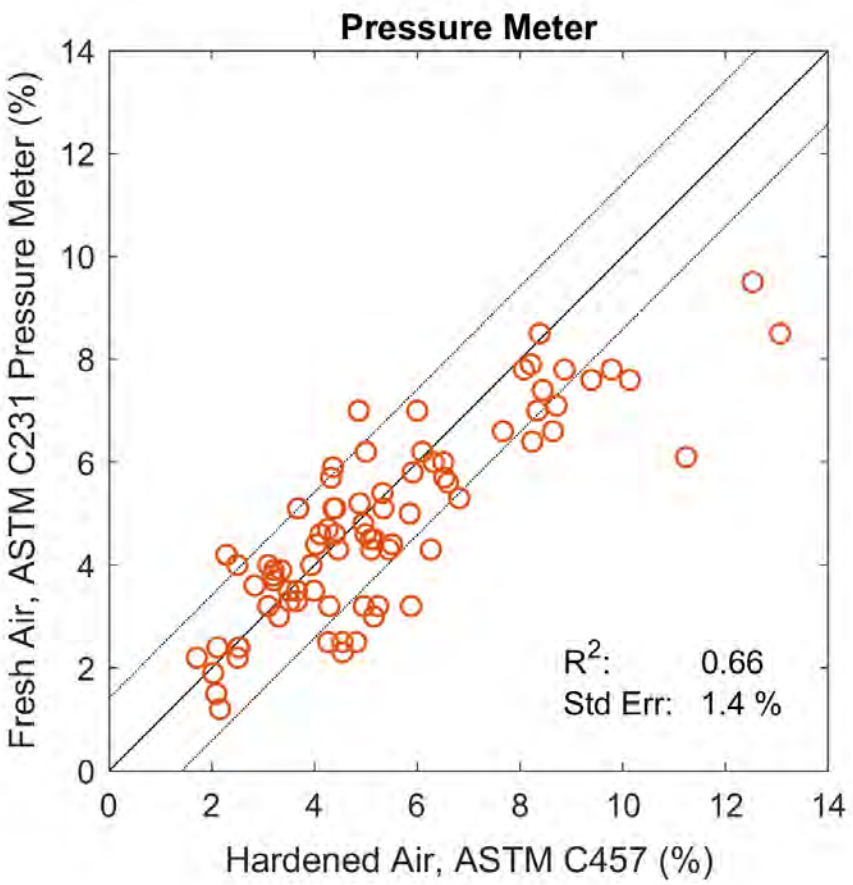
Achieved Air Diversity

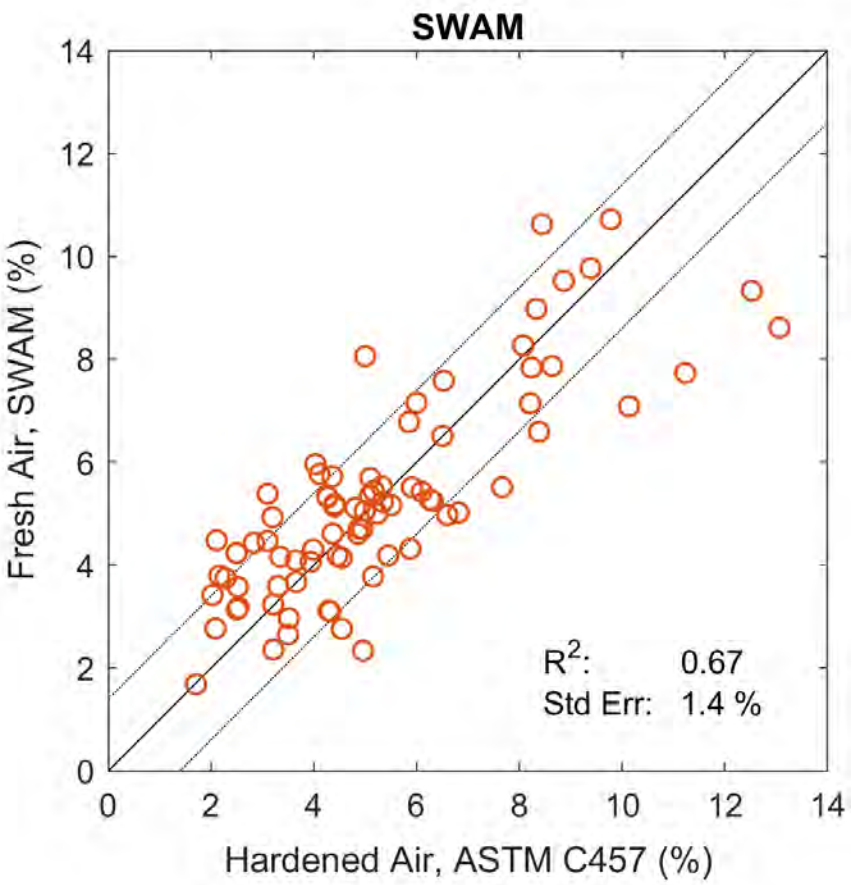


Fresh Air

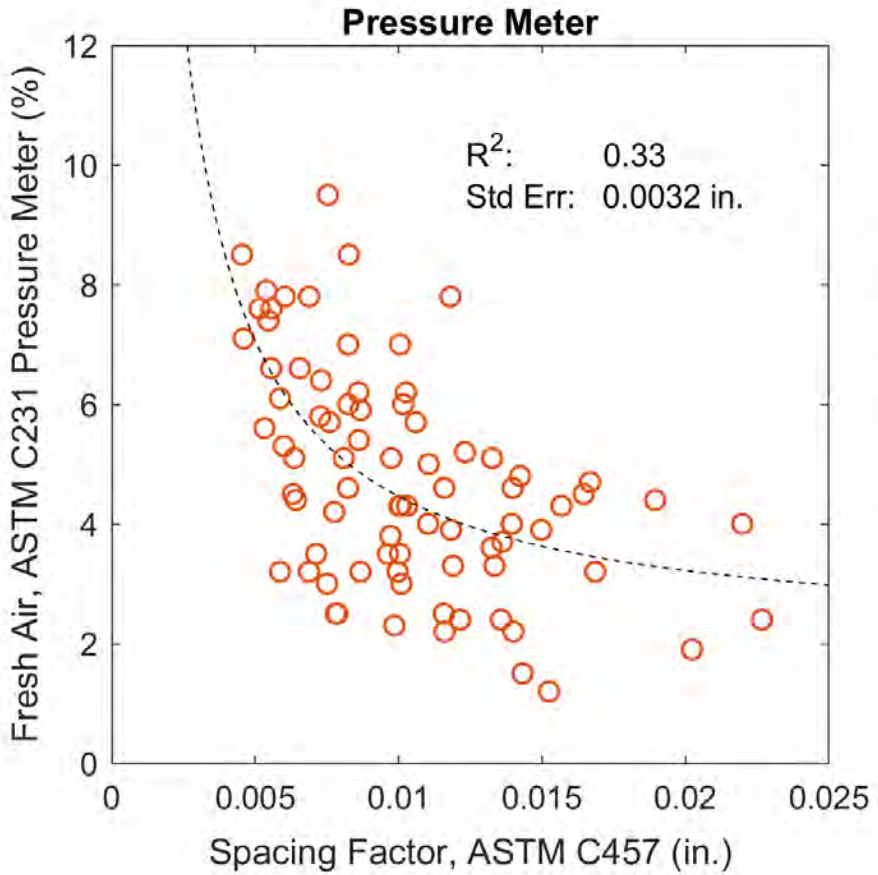


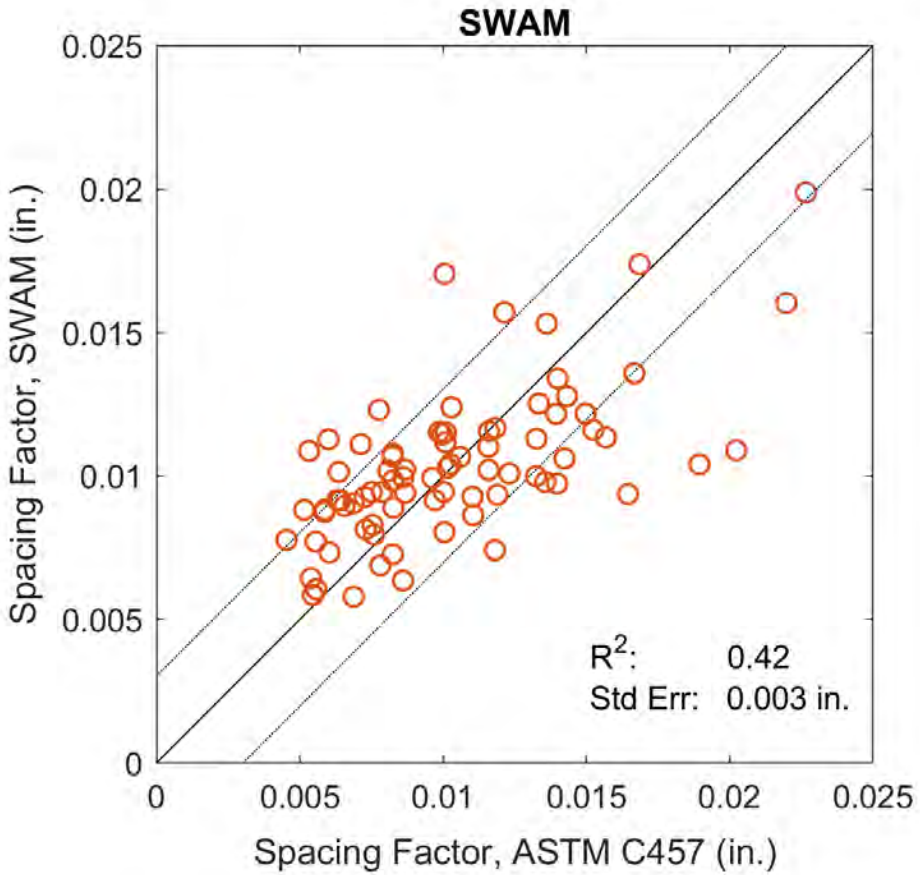
Hardened Air





Spacing Factor



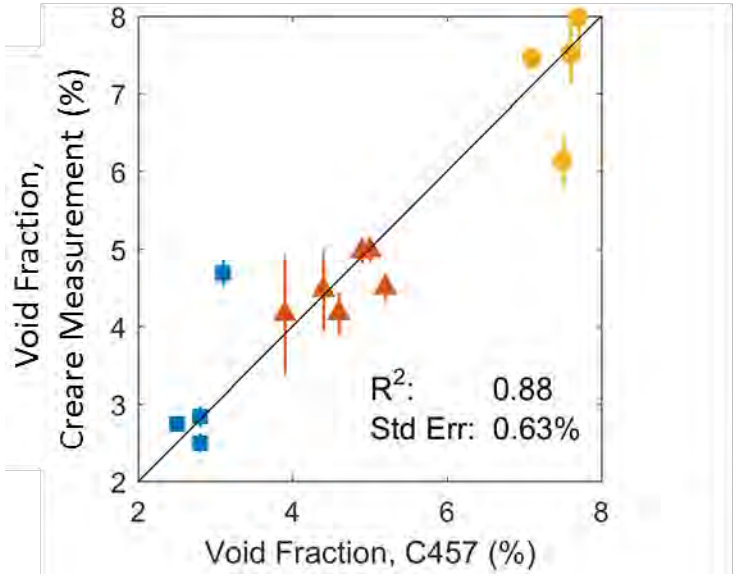


Initial Feasibility Experiment

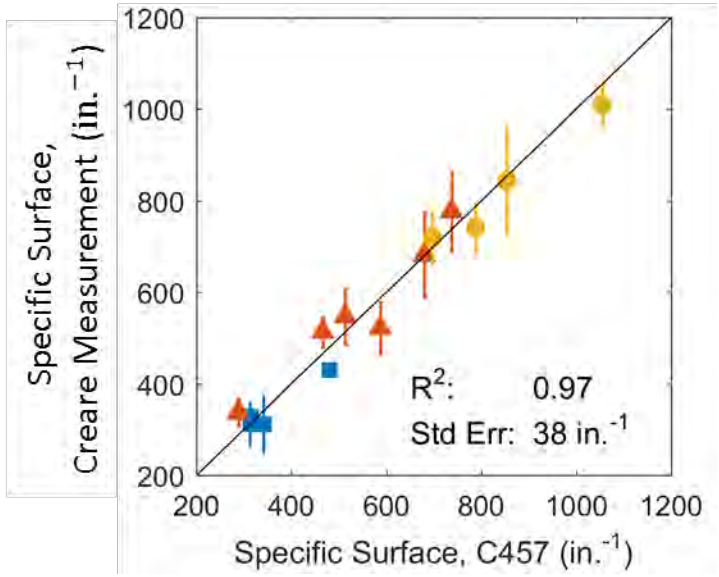
Feasibility Results

- **14 concrete samples**
  - **3/8″ aggregate**
  - **30% paste**
  - **Constant slump**
  - **Only one variable: AE admixtures**
- **SWAM**
  - **3 insertions, 3 measurements**
  - **2 different days**

Void Fraction



Specific Surface



Spacing Factor Troubleshooting

- **Traced problem to faulty O-ring in critical subsystem**
- **Initial laboratory testing with improved O-ring are encouraging**

Summary

- **SWAM:**
  - **Hardened Air**
    - **Standard error: ~1.4 percentage points**
    - **Similar to pressure/gravimetric methods**
  - **Hardened Spacing Factor**
    - **Standard error: ~0.003″**
    - **Slightly superior to existing fresh methods (AVA)**
  - **Quick, simple**
  - **Will get better:**
    - **More accurate specific surface → more accurate spacing factor**
    - **Battery powered, real-time display**
    - **Bluetooth / QR codes for data logging**

Discussion

- **Next Steps (2 years):**
  - **Fix O-ring (and other) issues and validate**
  - **Add user interface**
  - **Produce several “real” prototypes**
  - **Industry and DOT field trials**
    - **Always looking for potential field test opportunities**

Elastomer Calibration Articles

No Air **Moderate Air** **More Air**